1. **Project Name:** **High Density Infrared (HDI) Fusion of Wear and Corrosion Resistant Cermet and Hard Facing Coatings**

2. **Lead Organization:** Materials Resources International (MRi)
811 W. Fifth Street / Unit 2
Lansdale, PA 19446

3. **Principal Investigator:** Ron Smith
Ph: 215-631-7111/ Fax: 215-631-7115/Email: solution@voicenet.com

4. **Project Partners:**

Organization(s)	Type of Participation
MRi -Primary Industrial Partner Ronald W. Smith: Ph: 215-631-7111; Fax: 215-631-7115 Email: solution@voicenet.com	In-kind labor and facilities
Oak Ridge National Laboratory Gail Mackiewicz Ludtka: Ph: (865) 576-4652; Fax: (865) 574-4357; Email: ludtkagm@ornl.gov	R&D, materials characterization, processing and process modeling

Other Participants:

Ametek- Richard P. Mason	In-kind labor and Materials
Carpenter Powder Products- Lou Lherbier	In-kind labor and Materials
Crucible Research Division -Andrzej L. Wojcieszynski	In-kind labor and Materials
Lund International Corp.-Peter Zagaeski-	In-kind labor, materials, and prototype testing
St. Louis Metallizing-Klaus Doebler	In-kind labor and materials pre-processing

5. **Date Project Initiated:** April 2002 **and FY of Effort:** FY2003

6. **Expected Completion Date:** 6/01/05

7. **Project Technical Milestones and Schedule:**

The objective of this project is to develop and evaluate coating-substrate systems that result in wear and corrosion resistant coatings. The specific goals of this project are: (1) to understand the prominent material characteristics that influence coating-substrate fusion processes, (2.) to develop and/or utilize computational models to target and predict the thermal heat flux necessary to produce the structures that result in improved wear and corrosion resistant coating materials; and (3) to evaluate subsequent coating-substrate properties.

FY 2003 / 2002

Task / Milestone Description	Planned Completion	Status
1.0 Assess Applications & Needs	9/30/02	Completed
2.0 Materials Process Development	**3/31/04**	**In-progress**
• Evaluate initial thermal spray precursors	12/31/03	In-progress
• Identify materials systems	9/30/02	Completed
3.0 Fusing Process Development	**9/30/04**	**In-progress**
• Initial process studies	9/30/02	Completed
• Modeling	3/1/05	In-progress
4.0 Coating Testing and Evaluation	**3/1/05**	“ “
• Metallography, analysis, & mechanical testing	3/1/05	“ “
• Wear and corrosion studies	3/31/04	Planning in-progress
5.0 Field Testing	3/31/05	“ “
6.0 Reporting	**6/1/05**	**Required Quarterly Reports completed**

FY 2004

3.0 Fusing Process Development	**3/31/05**	**Continue**
• Processing studies	9/30/04	Continue
• Modeling	3/31/05	Continue
4.0 Coating Testing and Evaluation	**3/31/05**	**Continue**
5.0 Field Testing	**4/30/05**	**Continue**
6.0 Process Optimization	**4/30/05**	**Continue**
7.0 Final Report	**6/1/05**	**To be completed**

FY 2005

5.0 Field Testing	**4/30/05**	**Continue**
6.0 Process Optimization	**3/31/05**	**Continue**
7.0 Final Report	**6/1/05**	**To be completed**

8. Past Project Milestones and Accomplishments:

This project has selected and evaluated a range of cladding materials that have the potential to produce wear resistance and corrosion resistance. Fusion processes have been developed with varying degrees of success for a variety of coating/substrate material systems. Selected claddings included carbide reinforced suspensions and mats, tool steels, stainless steels and hard phase, self-fluxing coatings.

Results to date show that the High Density Infrared Lamp (HDI) processing can heat large surface areas and produce well-adhered and metallurgically fused claddings of various compositions. These HDI processed coatings have demonstrated (HDI's) capability of fusing various coating-substrate material systems, but also, highlighted its intricacies and the need for improved process understanding. Developments have shown that there are distinct differences in behaviors of the cladding compositions and their structures related to the thermal and chemical properties leading to difference in wetting, adherence and densification by fusing behavior. The project is now focusing on studying several "model" cladding systems, characterizing the thermophysical properties of these materials and preparing to conduct selected fusion trials that are well instrumented. Basic materials properties are being determined for input into computational models, now under development, so that thermal processing predictions can be tested and result in improved and optimized wear- and corrosion-resistant coating-substrate systems. It is expected that this fundamental approach to the studies will enable us to optimize the development of the fusing process. The models predictions will be tested and lead to HDI process improvements, better selection of HDI process conditions and ultimately lead to improved and better controlled HDI conditions for making a range of wear and corrosion resistant coatings for a range of industrial applications.

The results from the first 3 quarters in FY2003 underscored the need for current efforts to focus on designing fundamental and basic approaches to understanding how the HDI process interacts with precursor layers and substrates to form corrosion and wear resistant coatings. An experimental plan has been designed to develop and utilize computational models to predict heat flux processing parameters to optimize coating/substrate structures to provide wear- and corrosion-resistant coatings for a range of IOF industry applications. These models coupled with experimental results will provide a better understanding of the influence of the coating/substrate materials properties on the bonding characteristics and wear- and corrosion resistance of these materials. The following conclusions resulted from the effort completed thus far in FY2003:

Conclusions from thermally sprayed precursors (including Ni Self-Fluxing/Flame Spray Coatings, 316 L Stainless Steel/Flame Spray Coatings, 316L Stainless Steel/Plasma Spray Coatings, 316 Stainless Steel/HVOF Spray Coatings, Hastelloy/Plasma Spray Coatings, Hastelloy/Arc, Hastelloy/HVOF, H13 Tool Steel/Plasma, and H13 Tool Steel / High Velocity Oxygen Fuel (HVOF) sprayed coatings):

1. HVOF provides the most optimum thermal spray coating process for alloys such as stainless steel, tool steel and Hastelloy. The high density, low oxide content and good bonding promote best HDI behavior.
2. Plasma spray bonding is variable when spraying 316 Stainless and Hastelloy powders, leading to variable HDI fusion and densification.

3. There is a general "lack of wetting" when the molten metals do not contain B and Si. It is known that these two elements, and to some degree, chromium and phosphorous, promote liquid metal wetting of steel.
4. Coating delamination of 316L Stainless occurred and may be attributed to the rapid build up of Coefficient of Thermal Expansion (CTE) related stresses, which stress the bond line (i.e., 316 Stainless Steel and Hastelloy) and leads to debonding from the coated steel coupons.
5. H13 tool steel thermally sprayed layers require additional metallurgical analysis and process optimization.

Conclusions on Suspensions Precursors sprayed and HDI processed: (including TN660W (NiP/WC), TN745Cr (NiCrP/Cr3C2), and Tool Steel Suspensions (CPM10V, Rex 121, and Blends: TN alloys with Rex 121, and Blends: TN alloys with CPM 10V).

In general suspension coatings have produced the best coatings to date, although they are not yet optimized. The suspension precursor seems to have advantages. Some of the advantage could be related to the thinner nature of the suspension precursors. Efforts are focusing on thinner thermal spray precursor coatings.

1. The thermal parameters for successfully depositing and bonding a Ni-Cr-P alloy with WC have been determined.
2. The thermal parameters for successfully depositing and bonding a Ni-Cr-P alloy with Cr carbides have not yet been optimized.
3. Tool Steel blends with Ni-P and Ni-Cr-P without carbides become "too fluid" and do not uniformly coat the coupon surface. Metallographic analyses are in progress.

Conclusions on Nickel Cladding

The objective was to see if HDI could produce a more economical process than the current cladding methodology used for bonding nickel sheet to various substrates, and replace the more costly welding/rolling processes used now by Ametek.

1. It is apparent that an "under layer" other than a thin suspension layer will be needed to promote wetting and subsequent bonding to the substrate.

Based on the inherent complexity of the wear- and corrosions resistant coating/substrate systems required, continued efforts for this project will focus on detailed and fundamental materials studies and modeling development efforts.

9. Planned Future Milestones:

The issues to be addressed include: (1) Improved understanding and control of melting of the thermally sprayed precusor layers, (2) Lack of wetting of the steel substrates by the molten layers; and (3) Improvement of HDI fusion and densification of all coating types. Thermophysical properties thermal process modeling trials will assist in understanding the thermal flux required issues, and a focus on basic materials system parameters would eventually lead to improved HDI processes. The revised experimental plan, presented below addresses these fundamental elements to better understand the above issues:

- HDI / Coating-Substrate Thermal Modeling (October 31, 2003)
  - Initiate measurements of precursor layer thermal properties (C_p, k, and a) (May 30, 2003)
  - Evaluate thermal spray coating structure with thermal properties (September 30, 2003)
  - Compute thermal profiles based on properties (October 31, 2003)
- Complete Characterization of Thermal Spray layers (November 30, 2003)
  - Density / bonding
- Complete Characterization of Post HDI Layers (January 31, 2003)
  - Bonding
  - Structure

The focus will be on industrially selected "model" material systems (precursor/substrate) including: Ni-CrBSi Flame Spray Coating, Stainless Steel HVOF (high velocity oxy-fuel) spray coating, and Tool Steel (CPM) by HVOF, and Suspensions with Carbide and/or Tool Steel reinforcements. In addition to these basic studies, the project will also begin to focus on several wear and commercial applications, centering on Lund Agricultural Cutting Blades. Lund International, a project partner, is contributing samples of agricultural blades for thermal spray and suspension precursor layers.

10. Issues/Barriers: As discussed above, a fundamental and basic experimental plan has been designed to understanding how the HDI process interacts with precursor layers and substrates to form corrosion and wear coatings. This experimental plan has been devised to address and better understand the influence of the coating/substrate materia l properties on bonding characteristics.

11. Intended Market and Commercialization Plans/Progress: Currently, Lund International (a project partner) is preparing agricultural cutting blade samples for the application of thermal spray and suspension precursor layers. These blades will be HDI processed and installed into agricultural equipment and evaluated via industrial trials selected by Lund. Other applications that are of interest include: (1) Wear Inserts (e.g. for Steam valves), (2) Rolls, and (3) Aqueous Corrosion Resistant Thermal Spray Coatings. Successful completion of this project also would enable the application and repair of coatings in-the-field. This is extremely important to many vision industries, including Mining, Petrochemical, Pulp & Paper, Oil, Gas, and Metal Working. In addition, in many cases, more expensive alloys have to be utilized on larger structures due to the fact that wear or corrosion properties are needed in specific areas of the part. Consequently, this project would also allow the application of the appropriate wear or corrosion material just where it is needed.

12. Patents, publications, presentations:

Papers Presented at ASM Surface Engineering Conference / Columbus OH / Oct 02
Paper Presented at ASM/AWS Intl Brazing and Soldering Conference / San Diego CA / Feb 03.

HIGH DENSITY INFRARED FUSION OF WEAR AND CORROSION RESISTANT COATINGS

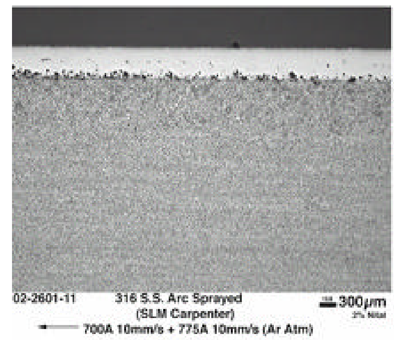
Objective: **Develop and evaluate wear- and corrosion- resistant coating-substrate systems.**

Benefits:

- Eliminates energy intensive and costly cladding processes

  -Heat input is tailored to utilize localized heating sufficient to fuse/bond coatings to base materials

- Rapid, high flux processing heats large surface areas and produce well-adhered, metallurgically fused claddings



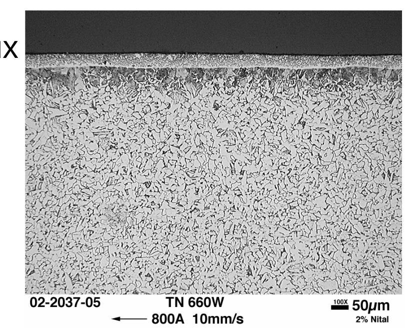
Significantly Reduced Coating Porosity

Status:

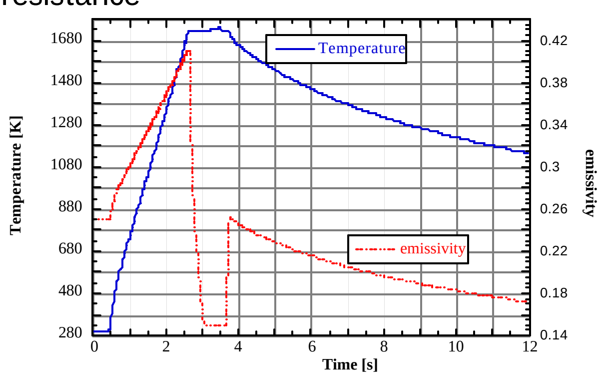
- Demonstrated well-adhered, metallurgically fused/bonded claddings of various compositions.

- Developments have shown that distinct differences in fusing behaviors of cladding compositions and their structures are related to the thermal and chemical properties leading to differences in wetting, adherence and densification

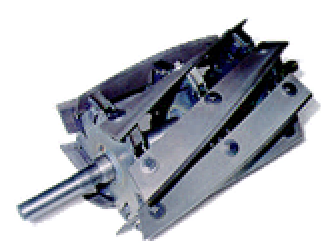
- Developed experimental model and plan to predict thermal flux and processing parameters to enhance wear- and corrosion resistance



Adherent, Fused Coating



Thermal Flux Modeling Helps Predict the Fusing Processing Parameters



Forging Knife Cutter Head

Project Partners:

- Materials Resources International, Ron W. Smith
- ORNL, Gail M. Ludtka
- Ametek, Carpenter, Crucible, Lund, and St. Louis Metallizing

Industrial Materials for the Future Impact Areas:

Mining, Petrochemical, Paper, Oil, Gas, and Metal Working